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RESEARCH MEMORANDUM

EFFECT OF VARIOUS BLADE MODIFICATIONS ON PERFORMANCE

OF A 16-STAGE AXIAL-FLOW COMPRESSOR

II - EFFECT ON OVER-ALL PERFORMANCE CHARACTERISTICS

OF INCREASING TWELFTH THROUGH FIFTEENTH STAGE

STATOR-BLADE ANGLES 30°

By James E. Hatch and Arthur A. Medeiros

Lewis Flight Propulsion Laboratory
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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

EFFECT OF VARIOUS BLADE MODIFICATIONS ON PERFORMANCE OF

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STATOR-BLADE ANGLES 3°

By James E. Hatch and Arthur A. Medeiros

SUMMARY

The stator-blade angles in the twelfth through fifteenth stages of a 16-stage axial-flow compressor were increased 3° in order to decrease the loading in these exit stages. The performance of this compressor configuration is compared with that of the same compressor with original blade angles. The peak efficiency was decreased by this modification from 3 points at 30 percent of the equivalent design speed to 12 points at 75 percent of the equivalent design speed. The peak efficiency was 79.5 percent for both configurations at 85 percent of the equivalent design speed. At design speed, the peak efficiency was reduced from 80 to 77 percent.

In order to evaluate the magnitude of the effect of changes in compressor performance on compressor-turbine matching characteristics, the equilibrium operating lines were calculated for an engine having a compressor with original blade angles and a two-stage turbine, and for an engine having a modified compressor and the same turbine. The compressor modification so shifted the operating line and the surge limit that the equilibrium operating line was deeper in the surge region at intermediate engine speeds.

A previous investigation has shown that increasing the loading in the exit stages by decreasing the stator-blade angles in the twelfth through fifteenth stages 3° results in improved part-speed performance with no change in design-speed performance; it is thus indicated that further improvement in the part-speed characteristics in this compressor, without too severe a penalty in design-speed performance, can be attained by decreasing the exit-stage stator-blade angles beyond 3° . However, the changes in performance obtained by decreasing the exit-stage stator-blade angles 3° was considerably less than that obtained by increasing these stator angles by 3° ; the optimum loading in the exit stages is therefore approached by the 3° decreased stator-blade angle settings.

INTRODUCTION

The effect of increasing the loading in the thirteenth through sixteenth stages on the over-all performance of a 16-stage axial-flow compressor is described in reference 1. The increased loading was accomplished by decreasing the stator-blade angles (measured with respect to the axis of the compressor) in the twelfth through fifteenth stages 3° . The modification resulted in improved part-speed efficiencies and an improved surge limit with no change in design-speed performance. This result indicated that part-speed performance could be considerably altered by reasonably slight changes in exit-stage stator-blade angles and that, in this compressor, further improvement in part-speed performance, without too severe a penalty at design speed, could be attained by some further decrease in exit-stage stator-blade angles. However, exit-stage stator blades with angle settings decreased more than 3° were not available at the time; an existing set of twelfth through fifteenth stage stator blades with angle settings increased 3° was therefore installed to determine the rate of change of compressor performance with deviation in stator-blade angles from the optimum setting. The over-all performance of this modified compressor was obtained at speeds of 30 to 100 percent of the equivalent design speed over a flow range from maximum flow to surge at each speed except at design speed where the surge pressure ratio was not determined. The test conducted at the NACA Lewis laboratory was similar to that described in reference 1 except that a 15,000-horsepower motor was used in this investigation.

DISCUSSION OF RESULTS

The over-all performance of the following three compressor configurations is shown in figure 1: the compressor with original blade angles (configuration A), the compressor with the twelfth through fifteenth stage stator-blade angles decreased 3° (configuration B), and the compressor with the twelfth through fifteenth stage stator-blade angles increased 3° (configuration C). The performance of configurations A and B is reported in reference 2 and is presented herein for comparison. At speeds below design, the angles of attack in the exit stages of configuration A become very low until at some speed the exit stages are turbinizing and limiting the weight flow through the compressor. This flow limitation forces the inlet stages to operate at angles of attack higher than those for which they were designed. These deviations from design angle of attack in the inlet and exit stages at speeds below design result in low part-speed over-all efficiencies.

Unloading the exit stages, as was done in configuration C, results in a more severe flow limitation; therefore, the deviation from design angle of attack in the inlet stages is greater, at any speed, for

configuration C than for configuration A. In addition, the angles of attack in the exit stages, which are lower than design at part speed, have been further decreased by increasing the stator blade angles in the twelfth through fifteenth stages. The deviations from design angle of attack are therefore greater for configuration C than for configuration A in both the inlet and exit stages, which results in lower part-speed efficiencies for configuration C. The decreases in peak efficiency, as shown in figure 1, range from 3 points at 30 percent of the equivalent design speed to 12 points at 75 percent of the equivalent design speed. At 85 percent of the equivalent design speed, the peak efficiency is 79.5 percent for both configurations A and C. At design speed, the peak efficiency is reduced from 80 to 77 percent. The surge pressure ratio was lower for configuration C at all speeds. However, because the weight flow at surge was also lower, the surge line in figure 1 for configuration C is only slightly lower than that for configuration A.

In order to evaluate the magnitude of the effect of changes in compressor performance on compressor-turbine matching characteristics, the methods of reference 3 were used to calculate the equilibrium operating line for an engine having compressor configuration A and a two-stage turbine, and for an engine having compressor configuration C and the same turbine. The over-all performance of the turbine is reported in reference 4. These operating lines and the surge limit for both configurations are presented in figure 2. The surge line was shifted to higher values of the compressor flow parameter at all speeds by unloading the exit stages of the compressor, and the equilibrium operating line was shifted to lower values of the compressor flow parameter because of the lower compressor efficiencies. Both these effects moved the operating line deeper into the surge region at intermediate engine speeds for the engine with the modified compressor.

In configuration B, the loading in the exit stages of the compressor was increased over that of configuration A; this resulted in increased weight flow at all speeds below design and, therefore, a lesser deviation with speed from design angle of attack in both the inlet and exit stages and a higher over-all compressor efficiency at part speed. The surge limit was also slightly improved by the increased loading. The performance at design speed was not changed by this modification, which indicates that, in this compressor, further improvement in part-speed efficiency and surge limit, without too severe a penalty in design-speed performance, could be attained by decreasing the stator-blade angles in the exit stages beyond 30° . However, the changes in performance achieved by decreasing the exit-stage stator-blade angles 30° was less than that obtained by increasing these blade angles 30° . Thus, the optimum loading in the exit stages is approached when stator-blade angles are decreased 30° .

SUMMARY OF RESULTS

Increasing the stator-blade angles 3° in the twelfth through fifteenth stages of a 16-stage axial-flow compressor produced the following results as compared with that of the compressor with original blade angles:

1. Peak efficiency was decreased from 3 points at 30 percent of the equivalent design speed to 12 points at 75 percent of the equivalent design speed. At 85 percent of the equivalent design speed, the peak efficiency was 79.5 percent for both configurations. The peak efficiency at design speed was reduced from 80 to 77 percent.

2. Calculated compressor-turbine characteristics indicated that the modification shifted the compressor surge limit to higher values of compressor flow parameter and the equilibrium operating line to lower values than those for an engine that had the original compressor-blade angles. The equilibrium operating line for an engine with the modified compressor would therefore lie deeper in the surge region than that for an engine with the compressor with original blade angles.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, January 5, 1952

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2. Medeiros, Arthur A., Hatch, James E., and Dugan, James F., Jr.: Effect of Various Blade Modifications on Performance of a 16-Stage Axial-Flow Compressor. I - Effect on Over-All Performance Characteristics of Decreasing Twelfth through Fifteenth Stage Stator-Blade Angles 3° . NACA RM E51L03 *Comp* *Effect* *Blade* *used*

3. Dugan, James F., Jr., Rebeske, John J., Jr., and Finger, Harold B.: Matching Characteristics of J35-A-23 Compressor and Two-Stage Turbine. NACA RM E51H15, 1951. *Comp* *Match* *in 50 J17*

4. Rebeske, John J., Jr., Berkey, William E., and Forrette, Robert E.: Over-All Performance of J35-A-23 Two-Stage Turbine. NACA RM E51E22, 1951. *Comp* *Perf*

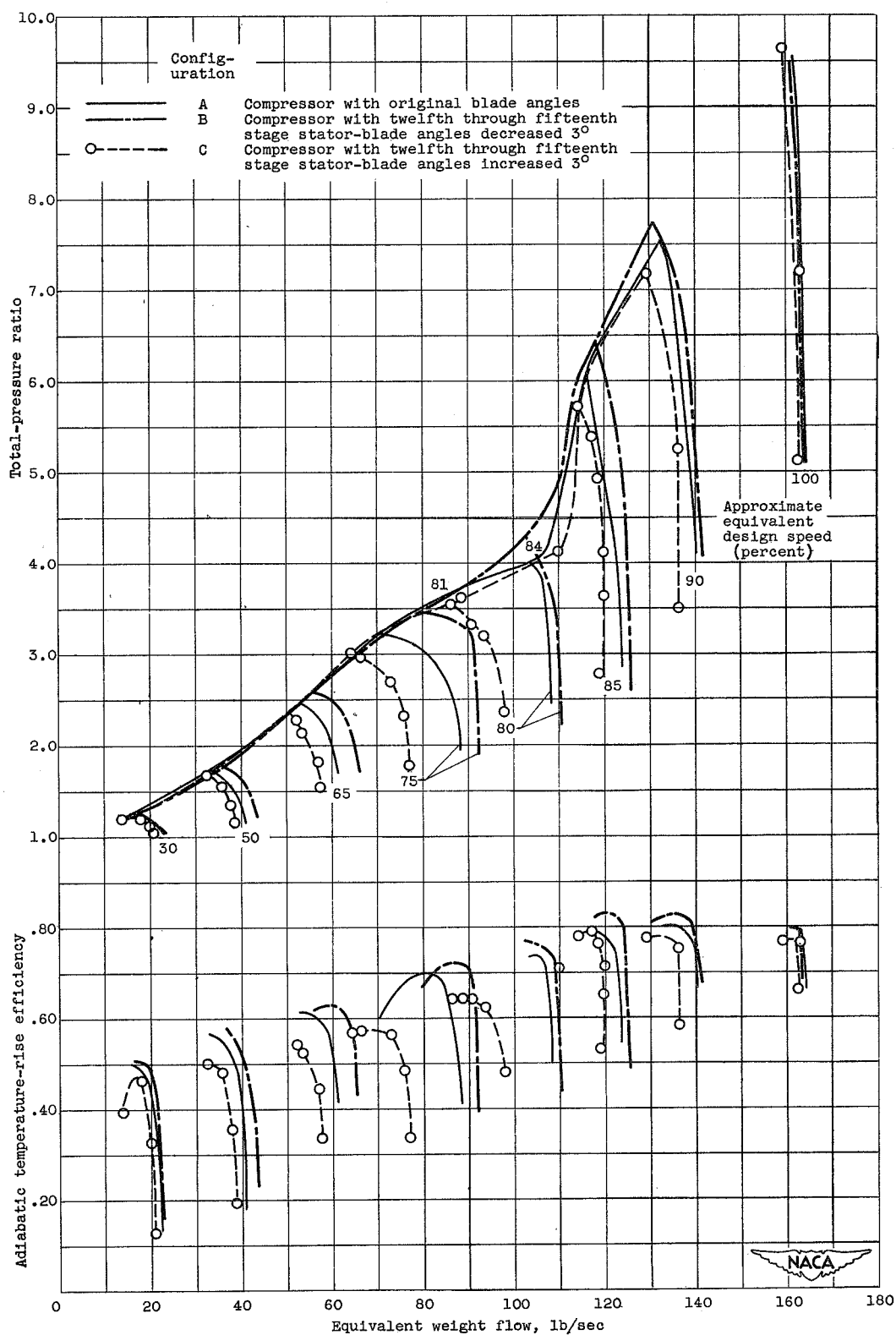


Figure 1. - Effect on over-all performance of changing twelfth through fifteenth stage stator-blade angles.

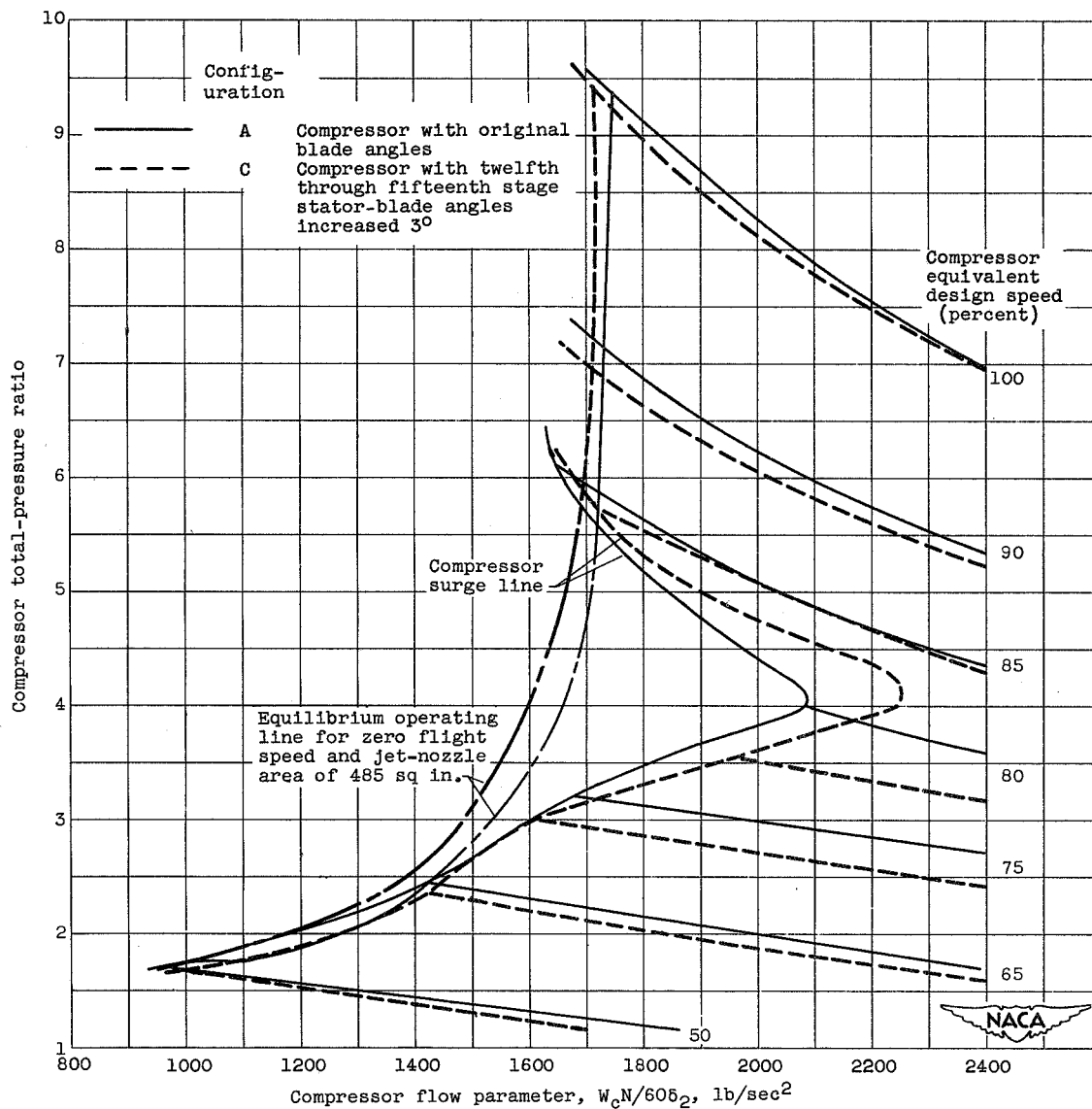


Figure 2. - Effect on matching characteristics of increasing twelfth through fifteenth stage stator-blade angles 3° . (Compressor weight flow, W_c , lb/sec; compressor speed, N , rpm; ratio of compressor outlet pressure to NACA standard sea-level pressure, δ_2 .)

RESEARCH MEMORANDUM

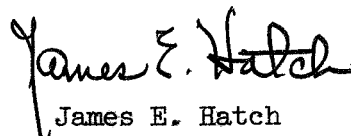
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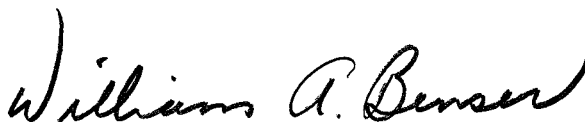


James E. Hatch
Aeronautical Research Scientist



Arthur A. Medeiros
Aeronautical Research Scientist

Approved:



William A. Benser
Aeronautical Research Scientist



Robert O. Bullock
Associate Chief, Compressor and
Turbine Research Division



Oscar W. Schey
Chief, Compressor and Turbine
Research Division

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Turbojets - Engines	3.1.3
Compressor - Axial Flow	3.6.1.1
Compressors - Matching	3.6.3
Turbines - Matching	3.7.4
Hatch, James E., and Medeiros, Arthur A.	

Abstract

The stator-blade angles in the twelfth through fifteenth stages of a 16-stage axial-flow compressor were increased 3° . The over-all performance of this modified compressor is compared to the performance of the compressor with original blade angles.

The matching characteristics of the modified compressor and a two-stage turbine were obtained and compared to those of the compressor with original blade angles and the same turbine.